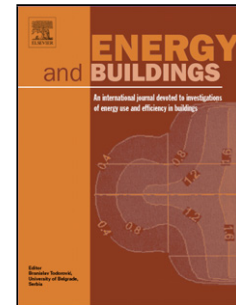


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**Experimental study and performance analysis of a solar thermoelectric air
conditioner with hot water supply**

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Abstract

The condensing heat recovery in air conditioner is attractive because of its great economical and environmental value. This paper presents theoretical and experimental investigations of a novel solar thermoelectric air conditioner with hot water supply (STACHWS). The system can implement different working modes according to the building users' requirement. Experiments were carried out under different operating conditions in order to investigate the performance of the system. Results show that the STEACWS can reliably be used to heat hot water without losing its cooling capacity when it is controlled well in different operation conditions. The system has relatively remarkable coefficient of performance (COP_{int}) which can be as high as about 4.51 in space cooling and water heating mode. When the system works as a water source thermoelectric heat pump, the coefficient of performance (COP) of the system can be about 2.59 in cooling mode and 3.01 in heating mode. This simple and environmentally friendly system can reduce indoor cooling and heating load and provide a continuous hot water supply for householders.

Keywords: Thermoelectric; Condenser heat; Hot water supply; COP

1. Introduction

About 15% of global electricity energy is consumed by various air conditioning and refrigeration processes, and 59% of the energy consumption in commercial and household buildings is attributed to air conditioning and water heating systems in 2011 [1]. Building energy conservation is of great significance nowadays. Usually, the heat of condensation from air conditioners will directly be discharged to the outside. This process is blamed for waste of energy as well as the thermal pollution to the outside environment. On the other hand, in order to meet building hot water supply, an external electrical or gas-fired boiler must operate all-day long. In this situation, the condensing heat in air conditioners has been attracting significant attention.

Many methods have been adopted on condensing heat recovery in vapor-compression air conditioning systems for condenser heat recovery. For instance, phase change material was used to restore the heat of the air conditioning system by Zhang et al. [2]. In addition, a helical heat exchanger was studied for heat recovery system by Yi et al. [3]. Because of its great economical and environmental value, the condensing heat recovery in vapor compression air conditioning systems had been applied to many engineering projects [4-6]. However, the traditional vapor compression system has some disadvantages:

(1) To meet the energy consumption of traditional vapor compression systems, natural resources are burned to generate electricity, which causes greenhouse effect and to exacerbate a lot of pollution on the earth. (2) The Freon in vapor compression system once leaked, will cause irreversible damage to the ozone sphere and make life suffer from ultraviolet radiation. Hence, a novel solar thermoelectric air conditioner integrated water heater system is proposed. The system uses thermoelectric modules powered by solar energy for heating hot water and cooling room simultaneously, therefore the system can reduce the utilization of traditional energy source, without doing any harm to the environment.

Thermoelectric material can be used in two major operating models: thermoelectric generator [7] and thermoelectric cooler (TEC) [8-9]. Thermoelectric cooler systems have no mechanical moving parts and do not employ working fluids, which can transfer heat from the cold side of the modules to the hotter side with consumption of electricity [10-11]. Due to the advantages such as high reliability, low weight, and flexibility in packaging and integration, the TEC systems are regarded as clean and active cooling methods, which have been widely used in military, aerospace, instrument, and industrial products [12-15]. In addition, due to their bright prospect, some thermoelectric applications are likely to be commercialized, such as air conditioners for domestic, thermoelectric ventilator, thermoelectric cooled ceiling, etc, which compete with vapor compression based applications [16-18]. Moreover, thermoelectric cooler system can be powered directly by a photovoltaic (PV), and no AC/DC inverter is needed. Therefore, it is recognized that the thermoelectric coolers and the solar cells combined system can be used for the air-conditioning applications, and the technology actually meets the demand for energy conservation and environment protection [19].

The main significance of this paper is to study the novel solar thermoelectric air conditioner integrated water heater technology in the application of low-carbon buildings. Compared with traditional thermoelectric air conditioner, the system can cool the room with thermoelectric powered by PV, at the same time, the water can be heated by the hot side of the TEC modules. Therefore, thermal energy can be recovered from the hot side of the thermoelectric module. Moreover, the system can work as a water source thermoelectric heat pump for space cooling in summer and space heating in winter. This system can reduce indoor cooling and heating load and provide hot water supply for uses. Thus, the novel system can be applied in a vast field.

2. The system working principle

Fig.1 illustrates the novel solar thermoelectric air conditioner with hot water supply system proposed for space cooling and hot water supply. As shown in Fig.1, the solar thermoelectric air conditioner with hot water supply (STACHWS) is divided into three parts: (1) the air part, (2) the TEC modules part, and (3) the water part. The PV system can provide a constant DC power supply during daytime, while batteries can provide power to the STEACWH system at night. According to the applications, the STEACWH system can be classified in the following operating modes:

(1) Space cooling and water heating mode: this mode is used in summer when space cooling and hot water are both required. When the system begins to work, the water tank is filled full with water. The return air is cooled down when it flows through heat exchangers into the indoor environment. At the same time, the water is heated up in the water tank by the heat exchanger on the other side of the TEC modules. Therefore, thermal energy can be recovered from the hot sides of TEC modules.

Fig.1. The working principle of the solar thermoelectric air conditioner with hot water supply

(2) Space cooling: This mode is the normal thermoelectric cooling mode for space cooling. Different from space cooling and water heating mode, the system work as a water source thermoelectric heat pump and the heat of the hot side of the thermoelectric modules is dissipated by flow water. The air is cooled down when it flows through heat exchangers moving into the indoor environment for space cooling.

(3) Space heating: In winter, revise the direction of current inputting the thermoelectric modules and then the heating side and cooling side reverse. The heat of the cold side of the thermoelectric modules is dissipated by the flow water. Then the system can work as a water source thermoelectric heat pump. The air is heated up when it flows through heat pipe exchangers moving into the indoor environment for space heating.

3. Theory of computer model

3.1 Mathematic model

Fig.2 depicts a prototype thermoelectric model developed for the design and analysis of STACHWS system. The TE modules are sandwiched between the hot and cold side heat exchangers. Heat is either absorbed or released at the junction when an electrical current is passed through the junction of dissimilar conductors. Reversing the direction of the current changes the direction of the heat flow.

Fig.2.Schematic diagram and simplified model of STACHWS

The following formulate show relations for the different parameters in the STACHWS system, and the formulate are useful for setting up the model.

Inside heat sink heat balance equations:

$$T_c = T_a - Q_c R_c \quad (\text{for cold side}) \quad (1)$$

$$T_h = Q_h R_h + T_w \quad (\text{for hot side}) \quad (2)$$

In the above equations, the air side heat sink thermal resistance R_c is 0.3 W^{-1} (when the air velocity is 3.2m/s) and R_h is 0.2 W^{-1} in space cooling and water heating mode, and when the system work as a water source thermoelectric heat pump, the thermal resistance of air side heat sink R_c is 0.3 W^{-1} (when the air velocity is 3.2m/s) and the water side heat sink thermal resistance R_h is 0.18 W^{-1} (when the flow rates of water is 2L/min) in cooling mode. These values were obtained by tested.

Average temperature of the hot side and cold side of the thermoelectric modules:

$$T_m = (T_h + T_c)/2 \quad (3)$$

Thermoelectric material seebeck coefficient of:

$$a = \frac{N_{new}}{71} \times \frac{(\alpha_1 T_h + \alpha_2 T_h^2/2 + \alpha_3 T_h^3/3 + \alpha_4 T_h^4/4) - (\alpha_1 T_c + \alpha_2 T_c^2/2 + \alpha_3 T_c^3/3 + \alpha_4 T_c^4/4)}{T_h - T_c} \quad (4)$$

$$\alpha_1 = 1.33450 \times 10^{-2},$$

$$\alpha_2 = -5.37574 \times 10^{-5}$$

$$\alpha_3 = 7.42731 \times 10^{-7}$$

$$\alpha_4 = -1.27141 \times 10^{-9}$$

Resistivity of thermoelectric material:

$$r = \frac{N_{new}}{71} \times \frac{6}{I_{new}} \times \frac{(r_1 T_h + r_2 T_h^2 / 2 + r_3 T_h^3 / 3 + r_4 T_h^4 / 4) - (r_1 T_c + r_2 T_c^2 / 2 + r_3 T_c^3 / 3 + r_4 T_c^4 / 4)}{T_h - T_c} \quad (5)$$

$$r_1 = 2.08317$$

$$r_2 = -1.98763 \times 10^{-2}$$

$$r_3 = 8.53832 \times 10^{-5}$$

$$r_4 = -9.03143 \times 10^{-8}$$

Thermal conductivity:

$$k = \frac{N_{new}}{71} \times \frac{I_{new}}{6} \times \frac{(k_1 T_h + k_2 T_h^2 / 2 + k_3 T_h^3 / 3 + k_4 T_h^4 / 4) - (k_1 T_c + k_2 T_c^2 / 2 + k_3 T_c^3 / 3 + k_4 T_c^4 / 4)}{T_h - T_c} \quad (6)$$

$$k_1 = 4.76218 \times 10^{-1}$$

$$k_2 = -3.89821 \times 10^{-6}$$

$$k_3 = -8.64864 \times 10^{-6}$$

$$k_4 = 2.20869 \times 10^{-8}$$

The amount of heat absorber at the cold junction (Q_c) and the heat dissipated at the hot junction (Q_h) is

given by [20-21]:

$$Q_c = aI(T_c + 273.15) - \frac{1}{2} I^2 r - k(T_h - T_c) \quad (7)$$

$$Q_h = aI(T_h + 273.15) + \frac{1}{2} I^2 r - k(T_h - T_c) \quad (8)$$

Where I is the operating current; T_c is the cold side temperature and T_h is the hot side temperature; R is

the thermoelectric module's electrical resistance ($R = 2N\sigma / G$); S is the thermoelectric module's

electrical resistance; and K is the thermoelectric module's thermal conductance ($K = 2NkG$). S , R and K

are the temperature dependent parameters. N refers to the total number of thermoelectric elements used

in each module. G is the geometric factor, and a , σ , K are the material properties for the specific the

type of the TE element. The values of S , R , and K are varying according to the average temperature of the thermo element T_m , the relations are supplied by [21].

The heat balance of the storage tank is calculated by:

$$Q_{\text{tank}} = C_{pw} M_w \Delta T \quad (9)$$

Where Q_{tank} is the gained heat of the water in storage tank, C_{pw} is the specific heat capacity of water which is 4200 kJ/(kg K), M_w stands for the mass of water in storage tank, ΔT represents the water temperature variation.

The heat balance between the storage tank and environment is calculated by:

$$Q_{\text{loss}} = K_1 S_1 (T_w - T_e) / L_1 \quad (10)$$

Where Q_{loss} is the heat transfer between the storage tank and environment, K_1 is the heat transfer coefficient of insulation material, which is 0.03 W/K.m, S_1 is the area of storage tank, which is 0.6 m², T_w is the water temperature in the storage tank. L_1 is the thickness of insulation, which is 1.5 cm.

The equation of fan is provided by:

$$P_{\text{fan}} = U_{\text{fan}} I_{\text{fan}} \quad (11)$$

Where P_{fan} is the power of fan, U_{fan} is the operating voltage of fan, and I_{fan} is the operating current of fan.

An integrated coefficient of performance (COP_{int}) is defined to estimate the energy utilization of the integrated system. The energy utilization of the system includes the effective cooling capacity Q_c and the effective heating water capacity, Q_h .

$$Q_{hw} = Q_h - Q_{\text{loss}} \quad (12)$$

$$\text{COP}_c = \frac{Q_c}{W + P_{\text{fan}}} \quad (13)$$

$$COP_h = \frac{Q_h}{W + P_{fan}} \quad (14)$$

$$COP_{int} = \frac{Q_c + Q_{hw}}{W + P_{fan}} \quad (15)$$

$$COP_{int \cdot w} = \frac{Q_{hw}}{W + P_{fan}} \quad (16)$$

Where W is the power of thermoelectric modules.

3.2 Structure of the model

In this work, a thermoelectric air conditioner with hot water supply (STACHWS) technology system is proposed. In order to better understand the performance of the system, a simulation model based on the equations in section 3.1 is set up to estimate the performance of the thermoelectric air conditioner with hot water supply. The flow chart of this model is shown in Fig.3.

Fig.3.Flow chart of the system simulation model

4. Experimental testing

The STACHWS prototype was fabricated and tested in an environmental chamber in the laboratory. It comprised two heat pipe sinks, twenty-four thermoelectric modules, a water tank and cool fan as shown in Fig.3. The TE modules are sandwiched between two heat pipe sinks. Thermal insulating material was filled on the gap between on the two heat sinks. The Thermal conducts between all contacting surfaces were improved by applying thermal grease. The water tank is 600 mm×300 mm×200mm. The water tank is made of Zinc Plating, which is 1.5mm thick. In order to reduce heat dissipation, the wall of water tank is packaged by 60mm thick insulation materials. The TE modules used in this study were purchased from FERROTEC Corporation [18]. The TE modules type is 9500/127/060 B. The power of the ventilator is 18 W and the air volume is 120m³/h.

Fig.4. Schematic diagrams of the experimental apparatus.

The temperature were recorded by means of PT100 using an Envada EN880 modular paperless process recorder logger with temperature sensors. The temperature sensor accuracy is ± 0.1 . At present, a DC power supply was used to power the TE module. The operating voltage and current can be read by the LCD display. In the experimental studying the thermoelectric system's performance characteristics, the air temperature of the lab room was maintained at 26 in summer mode and 18 in winter mode. The tests were carried out in space cooling and water heating mode, space cooling mode and heating mode. In space cooling and water heating mode, the water tank is filled with water. And the heat of the hot side of the thermoelectric modules is dissipated by the flow water when the system works as a water source thermoelectric heat pump.

5. Results and analysis

5.1 Simulation and experimental results

In this section, simulation results and experimental results under different operation conditions will be presented and discussed to analyze the performance of the STACHWS system. The indoor environment temperature and humidity is set up as constant in the simulation process in summer and winter mode. As a result, the temperature of the air coming into the STACHWS is taken as constants. The experiment results for the hot and cold side temperature varied with the temperature of hot water compared with the simulation dates in space cooling and water heating mode are shown in Fig.5. It can be observed that the hot side temperature (T_h) keeps increasing rapidly with the hot water temperature increase, at the same time, the cold side temperature (T_c) increases simultaneously but more slowly compared with the hot side temperature (T_h) , therefore the temperature difference between the hot and cold sides becomes larger.

Fig.5.The hot and cold side temperature under different water temperature in space cooling and water heating mode

Fig.6 presents cooling and heating capacity of the system under an operating voltage of 5V with the hot water temperature increases in space cooling and water heating mode. As can be seen, the cooling and heating capacity of the system was relatively high and decrease as the water temperature increase. The cooling and heating capacity are 430W and 652W separately when the water temperature is 20 °C, and when the water temperature increase to 42 °C, the cooling and heating capacity are 178W and 353W. The reason behind this phenomenon was that the temperature difference between the hot and cold sides increases with the water temperature increases as shown in Fig5. According to the equation 1, the higher the temperature difference between the cold and hot sides, the lower the cooling and heating capacity is.

Fig.6. Cooling and heating capacity under different water temperature in space cooling and water heating mode

Fig.7 presents the $COP_{int,w}$ and COP_{int} of the system under an operating voltage of 5V with the water temperature increases in space cooling and water heating mode. As shown in Fig.7, the simulations and experiment results share the same trend and regularity in space cooling and water heating mode. As can be seen, the $COP_{int,w}$ and COP_{int} increased first to its maximum, and then decreased gradually when the water temperature increased as shown in Fig7. The maximum COP_{int} is 4.6. It is indicated that the system require less electrical energy and works more efficiently with lower water temperature in space cooling and water heating mode. The $COP_{int,w}$ decreased from 2.71 to 1.82 when the hot water temperature increased from 20 °C to 42 °C. It was conclude that the $COP_{int,w}$ played an important role in COP_w of the prototype in space cooling and water heating mode.

Fig.7. COP under different water temperatures in space cooling and water heating mode

Space cooling mode is usually used in summer. Different from space cooling and water heating mode, the hot side of the thermoelectric system absorbed heat from flow water in space cooling mode. As a result, the performance of the system can be improved, as the heat dissipation on the hot sides of the TEC modules is better than in space cooling and water heating mode. The flow rate of heat medium on hot side is 2L/min. Fig.8 presents the cooling capacity and COP_c of the system under an operating voltage of 4V with different water inlet temperature in space cooling mode. The lower water inlet temperature contributes the higher the performance of the system. As can be seen, the maximum COP_c of the system is 2.4 when the system works stably under the water inlet temperature of 12 °C.

Fig.8. Cooling capacity and COP_c under different water inlet temperature in space cooling mode

In winter, reverse the current direction inputting the thermoelectric modules and the cold side of the thermoelectric system absorbed heat from the flow water, then the system work as a water source thermoelectric heat pump. The flow rate of heat medium on cold side is 2L/min. Fig.8 shows the heating capacity and COP of simulations and experiments under different water inlet temperature when the voltage is 4V. The results were recorded when the system works stably. As shown in Fig8, the water inlet temperature has an important effect on the performance of the system in space heating mode. The heating capacity and the COP of the system decreased when the water inlet temperature increased. The COP_h can be reached at 3.05 when the water inlet temperature is 24 °C, which is more efficient than electric heater and also is larger than COP of 2.6 which is required the performance of air-source heat pump air conditioner in China.

Fig.9. Heating capacity and COP_h under different water temperature in space heating mode

As shown in Figs.5-9, there is certain difference between modeling and experimental results. The values of theoretical coefficient of performance are always higher than the experiment data. Table 1 shows the values of hot and cold side temperature for the modeling and experimental data and the relative deviation. There is certain difference between modeling and experimental results due to a number of factors, such as the measurement inaccuracy, the material property difference and the difference between ideal and actual thermal resistance of heat exchangers. It also can be seen from Table 1, the relative deviations between the simulations and experiments are small, it indicated that the simulations result and the experiment results are agree well with each other.

Table 1 Comparison of the hot and cold side temperature for modeling and testing

5.2. System optimization

The STACHWS system can be designed based on two principles, namely, the principle of maximized COPint, which is adopted in the design of STACHWS system and the principle of maximized cooling and heating capacity. The impact of electric current on COPint is shown in Fig.10. As can be seen, there is an optimum current (I_{op}) that let COPint have the maximum value. I_{op} is relevant to the water temperature. Larger water temperature leads to a high I_{op} but a low COPint. When the STACHWS system work in space cooling and water heating mode, it can be observed that, there is an optimum COPint existing when electric current is about 0.8 to 1.4A under different water temperature, larger or lower current rate is unhelpful to improve COPint. In space cooling and water heating mode, it can change the current of the STACHWS system under different water temperature in order to get a better performance.

Fig. 10 Impact of electric current on COPint

6. Discussion

According to the test and simulation results, the maximum COP of the novel solar thermoelectric air conditioner with hot water supply is 2.59 in cooling mode and 3.01 in heating mode when the system works as a water source thermoelectric heat pump. And when the system work in space cooling and water heating mode, the COPint is decreases from 4.51 to 2.74 when the hot water temperature increase from 20 to 42 . This value is higher than conventional split-type air conditioner (2.4 in average) and is more efficient than an electrical heating device, therefore it becomes more attractive. The TEC system performance is closely related to the figure of merit of thermoelectric materials, ZT, the TE modules used in this paper has a ZT of 0.61, which is not high considering the progress of TE technology. It is achievable since the latest quantum well materials have a ZT as high as 2.4 at 300 K [22], and when TE materials that have a $ZT = 2$, the COP of thermoelectric air conditioner can reach that of vapor compression coolers in climate-control applications [23]. Moreover, the performance of the STACHWS can be further improved by optimizing design and fabrication based on experimental data.

In the present experiments, the STACHWS system is powered by a DC power supply, this power will be replaced by a PV system in further studies. In daytime, the PV systems receive solar energy and turn it into electric power supplied to thermoelectric modules. If the electric power production is larger enough, the surplus power can be accumulated in storage battery besides driving the STACHWS system. Moreover, if the PV systems cannot produce enough electric power, for example, in rainy days, the storage battery may offer a makeup. The PV system and battery is controlled by an auto-switcher, which can play a role to maintain the energy conversion process in most optimized way.

7. Conclusions

In this study, a solar thermoelectric air conditioner with hot water supply (STACHWS) is proposed and tested. The system can shift flexibly between different working modes according to the building users' requirement. The system can be powered using renewable energies, in particular PV system, which produces DC electricity. Experiments were carried out under different operating conditions in order to investigate the performance of the system. The conclusions reached in the present study are listed as follows:

(1) The simulations result and the experiment results are agree well with each other. It indicated that the system could reliably be used to heat hot water without losing its cooling capacity.

(2) The results show that the performance of the STACHWS system is strongly influenced by water temperature. The COP_{int} decrease as the water temperature increase in space cooling and water heating mode. The system has relatively large coefficient of performance (COP_{int}) which can be as high as about 4.51 when the water temperature of 20 °C and 2.74 at water temperature of 42 °C.

(3) When the system works as a water source thermoelectric heat pump, the system works more efficiently with lower water inlet temperature in cooling mode and higher water inlet temperature in heating mode. The coefficient of performance (COP) of the system can be about 2.59 when the inlet water temperature of 12 °C and 1.86 at the inlet water temperature of 28 °C in cooling mode. In heating mode, the COP of the system is 3.01 when the water inlet temperature is 24 °C and 2.01 when the water temperature of 8 °C.

(4) The performance of the system can be improved by the optimization operating voltage, reducing the heat transfer resistance, especially the heat transfer resistance on the hot side of the thermoelectric modules. The thermoelectric module used in this work has a figure of merit ZT value of 0.65, and if the TE modules used in this paper has a ZT of 0.61, which is not high considering the progress of TE

technology. And when TE materials that have a $ZT = 2$, the COP and energy conservation ratio of the system could be further increased.

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Abbreviates of parameters:

COP_{int} – the integrated coefficient of performance is defined to estimate the energy utilization of the integrated system

$COP_{int,w}$ – it is that the COP_{int} is simplified when the cooling capacitive is equal to zero

T_w – the water temperature (),

T_{wi} – the water inlet temperature of the system (),

COP_c – system cooling coefficient of performance,

COP_h – system heating coefficient of performance,

I – applied current of TE module (A),

Q_c – The cooling capacity of the TE modules at the cold junction (W),

Q_h – The heating capacity of the TE modules at the hot junction (W),

T_c – cold side of temperature of TE module (),

T_h – hot side temperature of TE module (),

T_i – air temperature of indoor (),

ΔT – temperature difference of TE module (),

V – applied voltage of TE module (V),

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Figures captions

Table 1 Comparison of the hot and cold side temperature for modeling and testing

Fig.1.The working principle of the solar thermoelectric air conditioner with hot water supply

Fig.2.Schematic diagram and simplified model of STACHWS

Fig.3.Flow chart of the system simulation model

Fig.4. Schematic diagrams of the experimental apparatus.

Fig.5.The hot and cold side temperature under different water temperature in space cooling and water heating mode

Fig.6. Cooling and heating capacity under different water temperature in space cooling and water heating mode

Fig.7. COP under different water temperatures in space cooling and water heating mode

428

429 Fig.8. Cooling capacity and COP_c under different water inlet temperature in space cooling mode

430 Fig.9. Heating capacity and COP_h under different water temperature in space heating mode

431 Fig. 10 Impact of electric current on COP_{int}

432

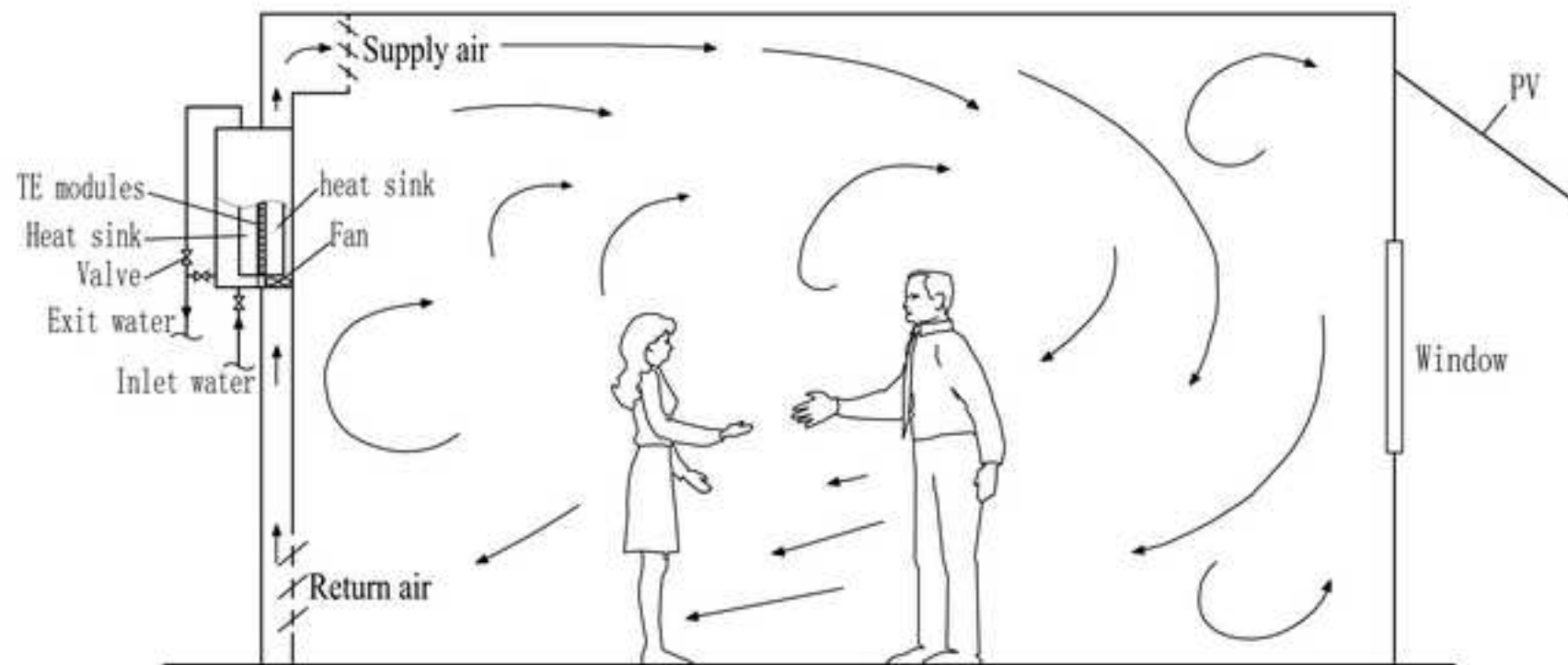
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Table 1 Comparison of the hot and cold side temperature for modeling and testing

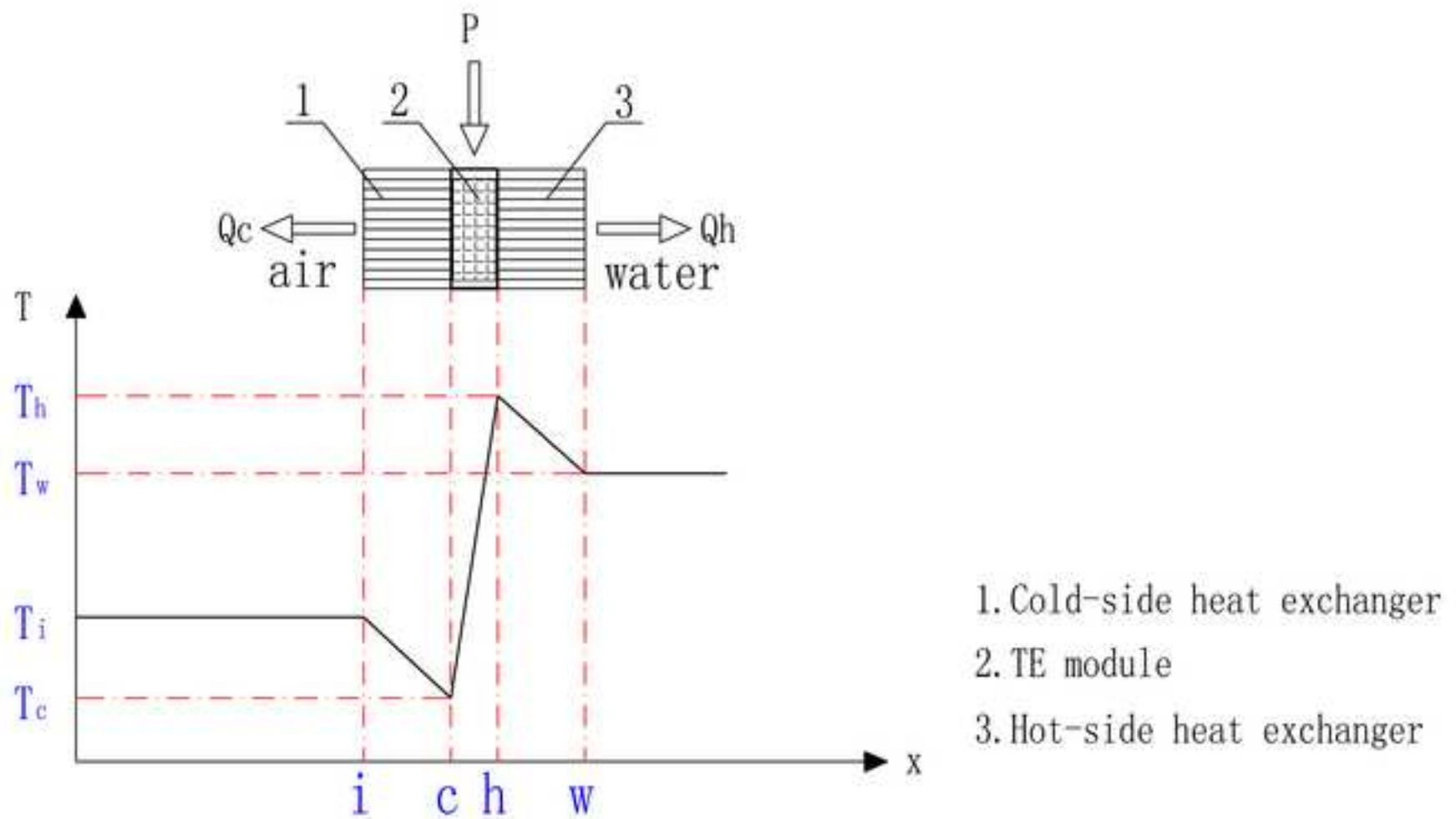
Operating mode	Operating condition	T_h ()			T_c ()		
		Simulation	Experiment	$\delta(\%)$	Simulation	Experiment	$\delta(\%)$
Space cooling and water heating	20 (T_w)	25.6	26.5	-3.5	15.0	14.8	1.3
	42 (T_w)	45.1	45.5	-0.9	21.4	21.2	0.9
Space cooling	12 (T_{wi})	18.9	19.3	-2.1	14.8	14.4	2.7
	24 (T_{wi})	29.2	29.4	-0.7	18.2	17.6	3.3
Space heating	16 (T_{wi})	27.4	27.8	-1.5	12.6	12.5	0.8
	24 (T_{wi})	29.6	30.2	-2.0	19.6	19.4	1.0

- 435 ▶ A novel solar thermoelectric air conditioner with hot water supply system was proposed.
- 436 ▶ A simulation model for thermoelectric system was developed.
- 437 ▶ A simulation program and experiments are conducted to identify the performance.
- 438 ▶ The coefficient of performance which can be as high as about 4.51 in space cooling and water heating
- 439 mode.
- 440

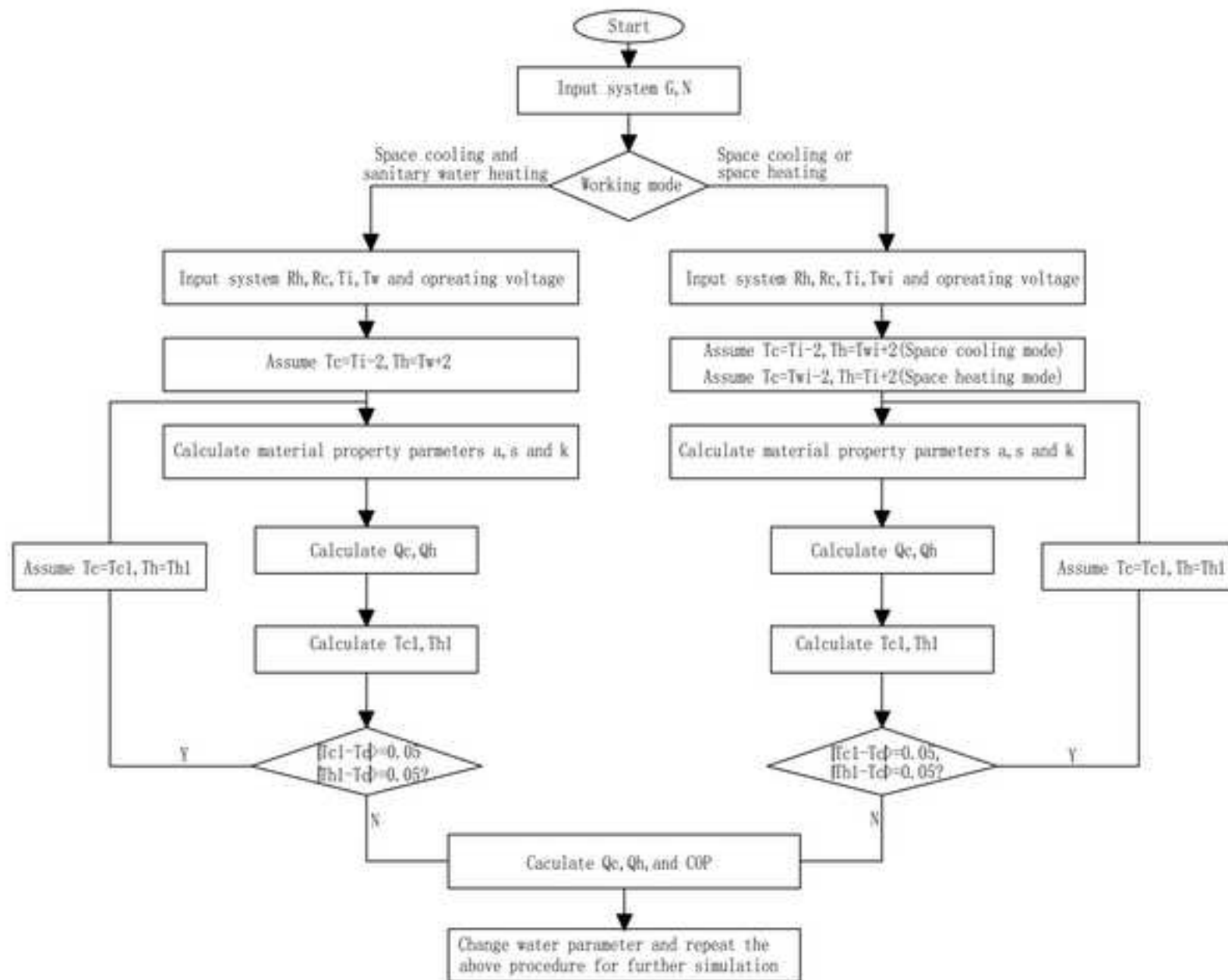
Figure(1)



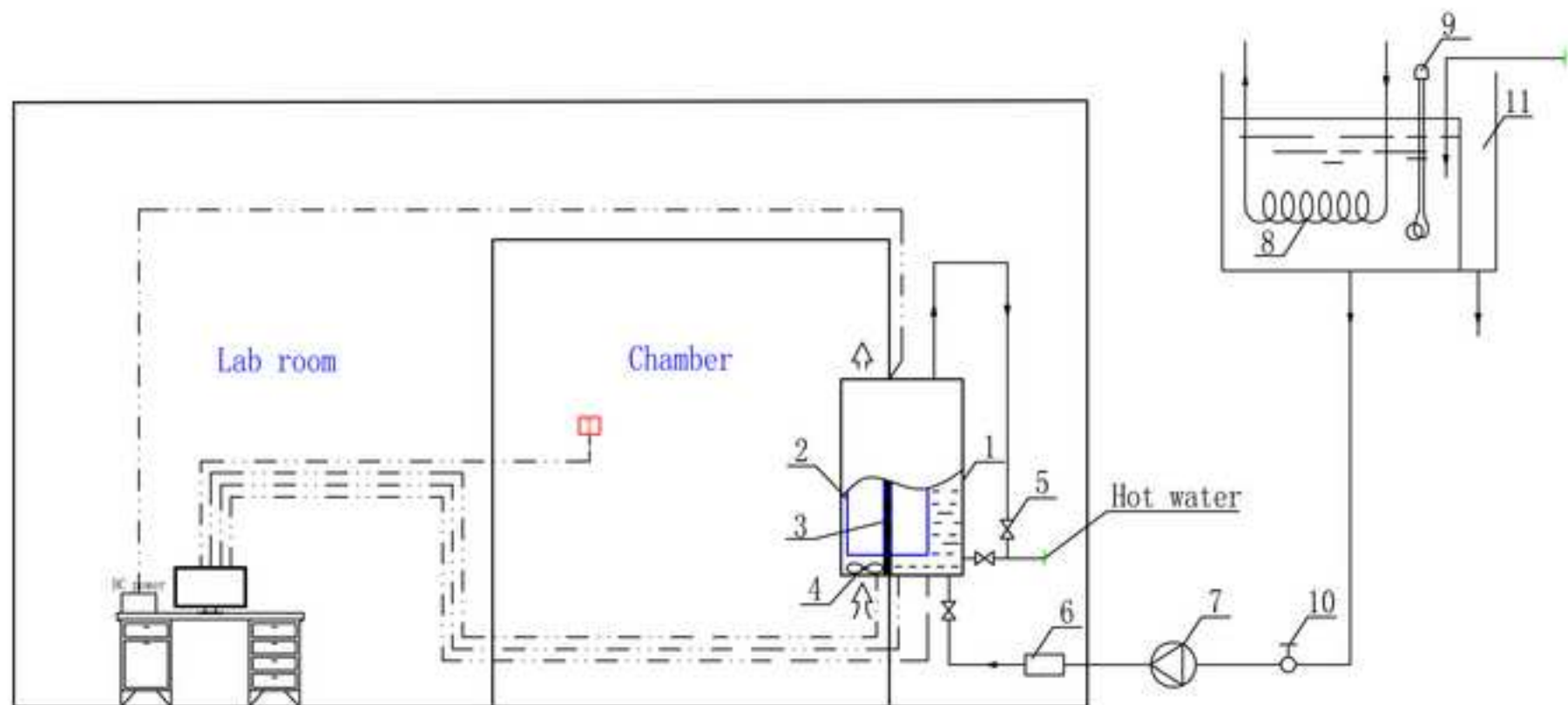
Figure(2)



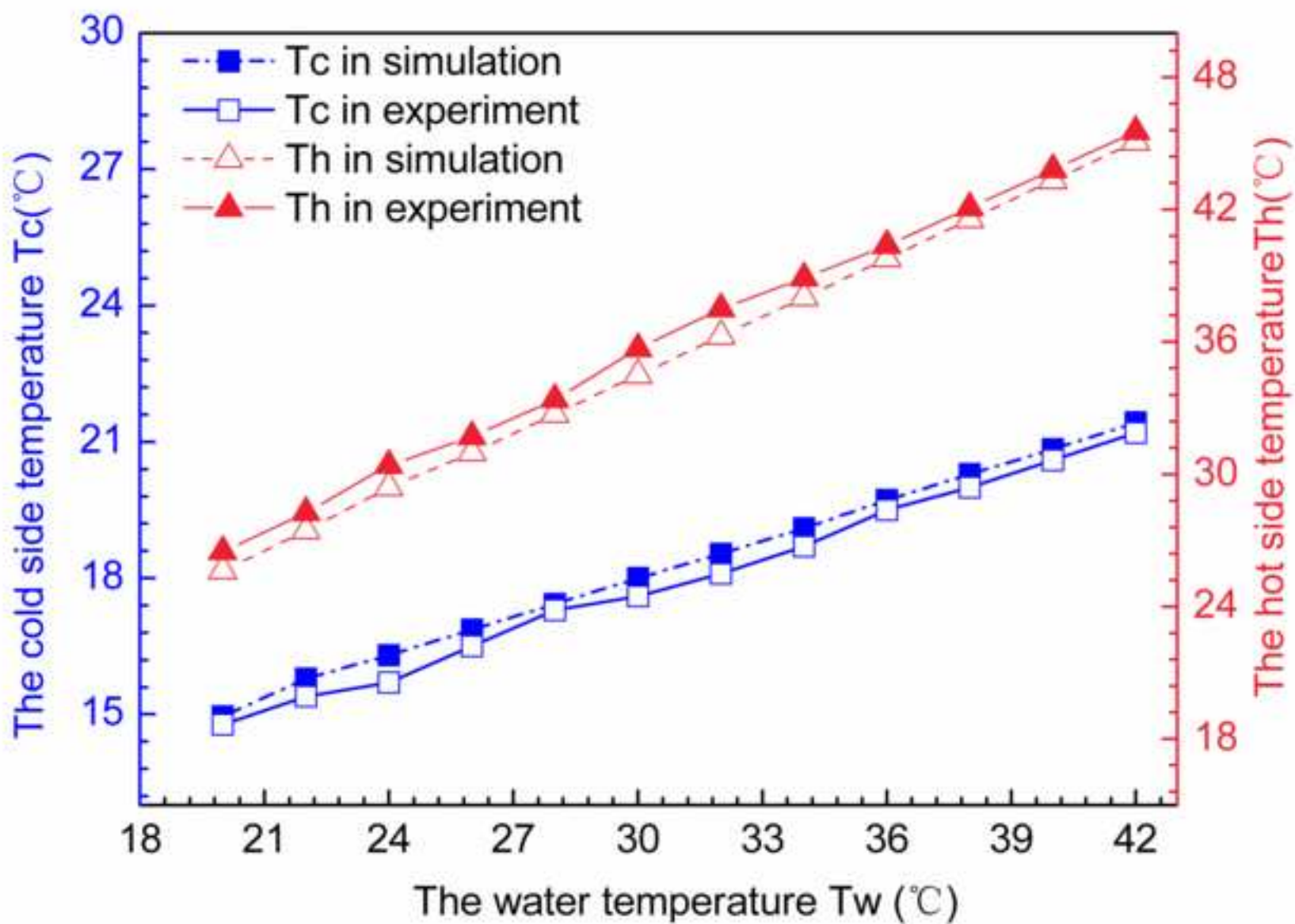
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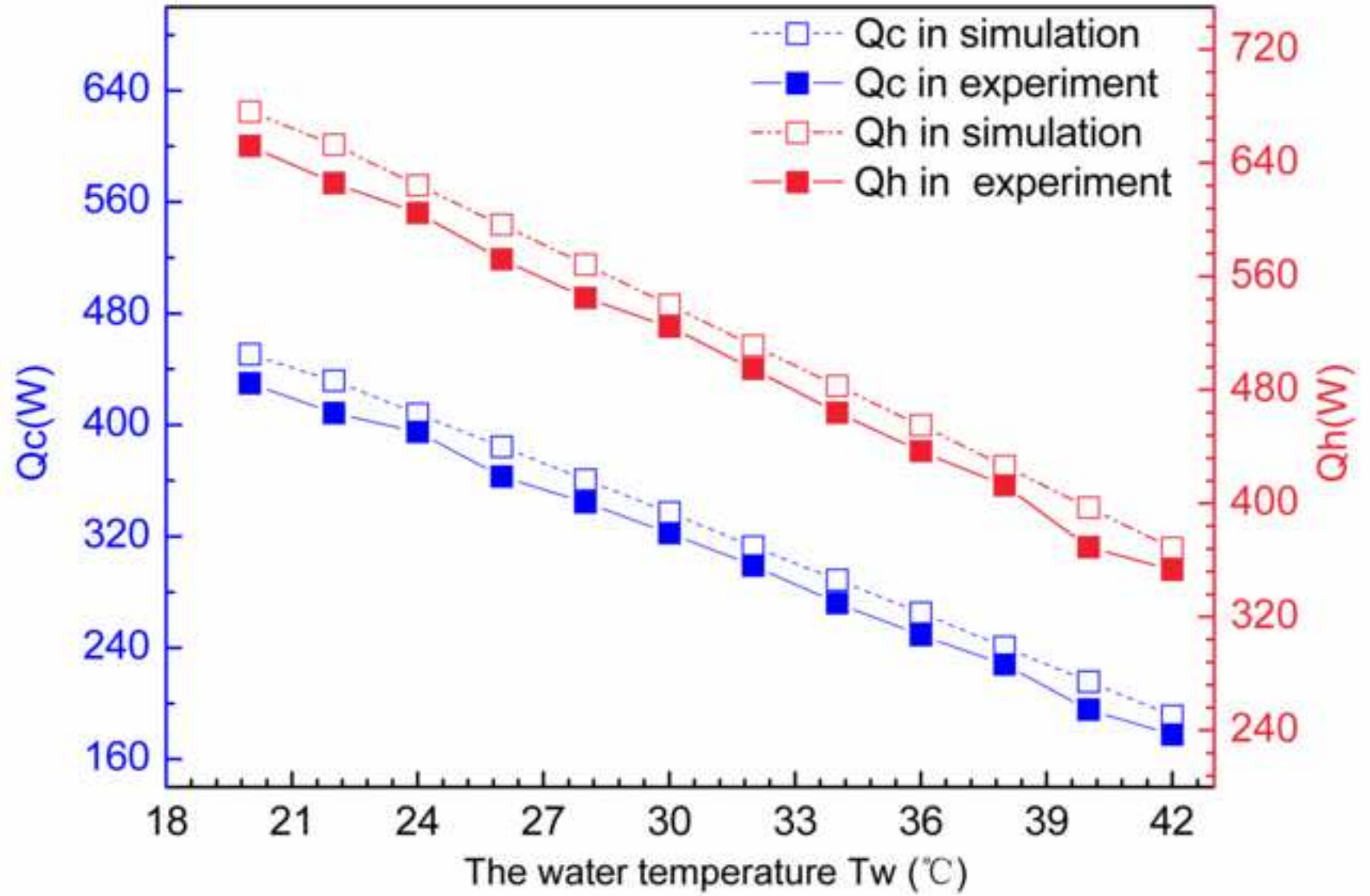
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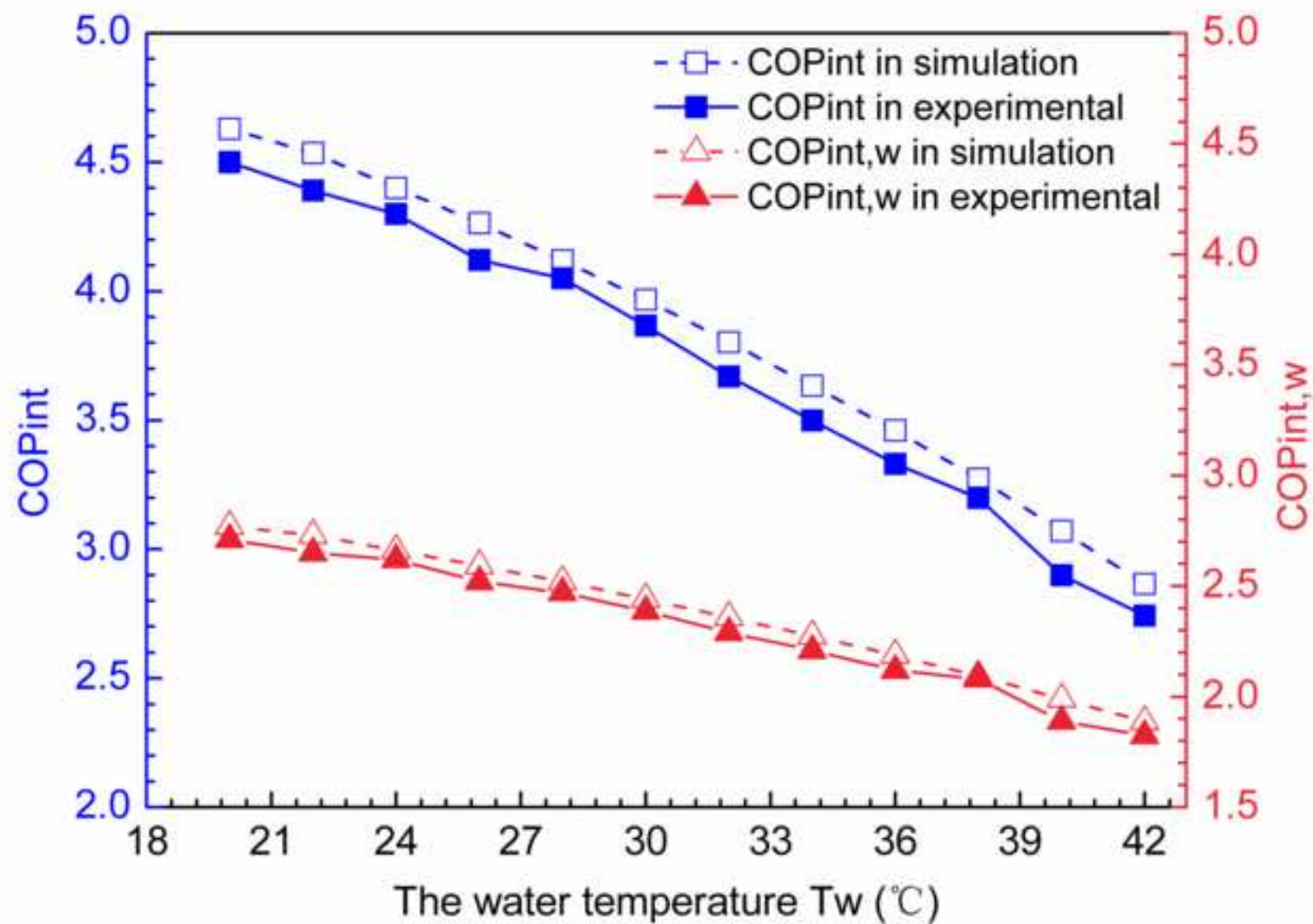
Figure(5)



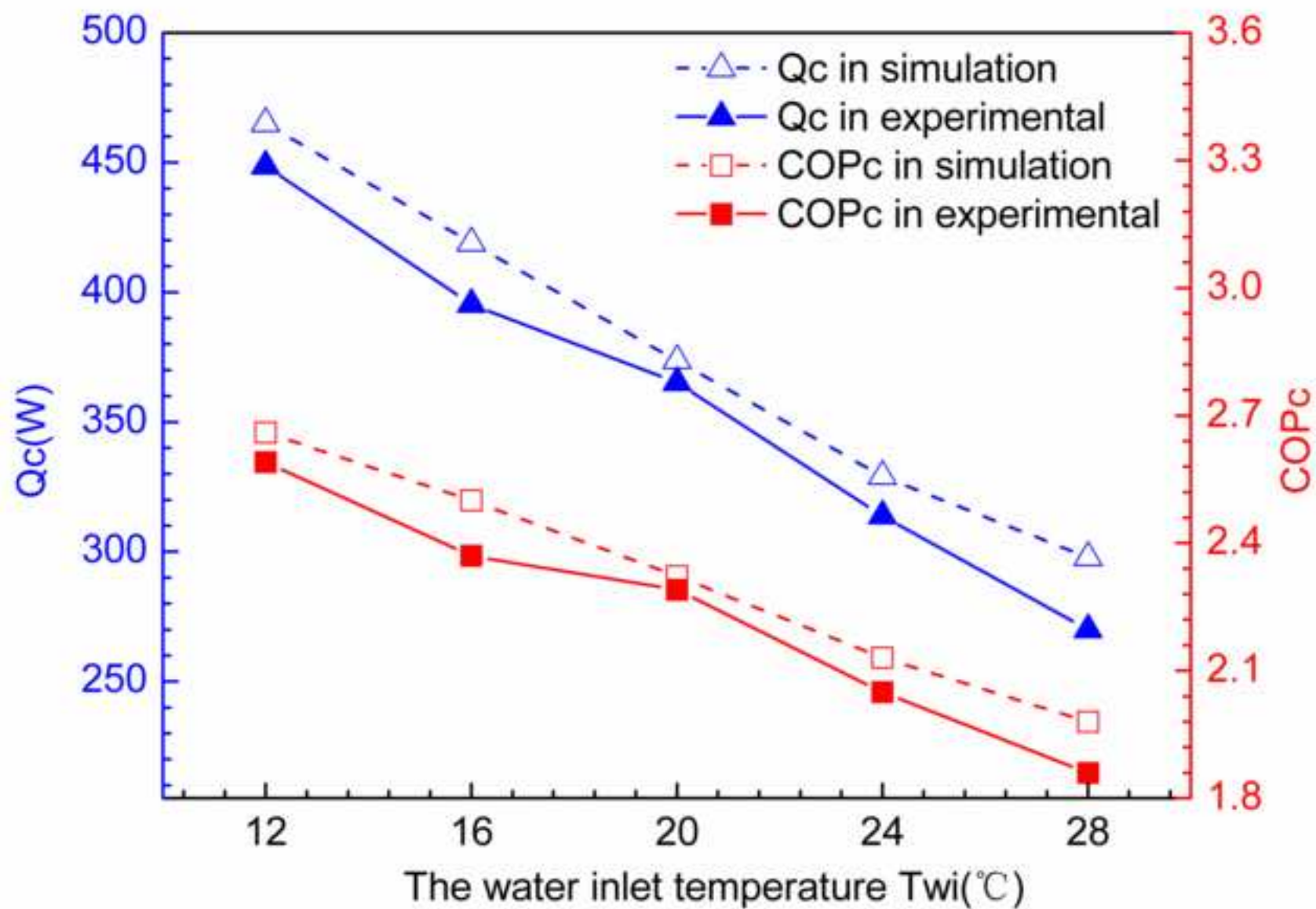
Figure(6)



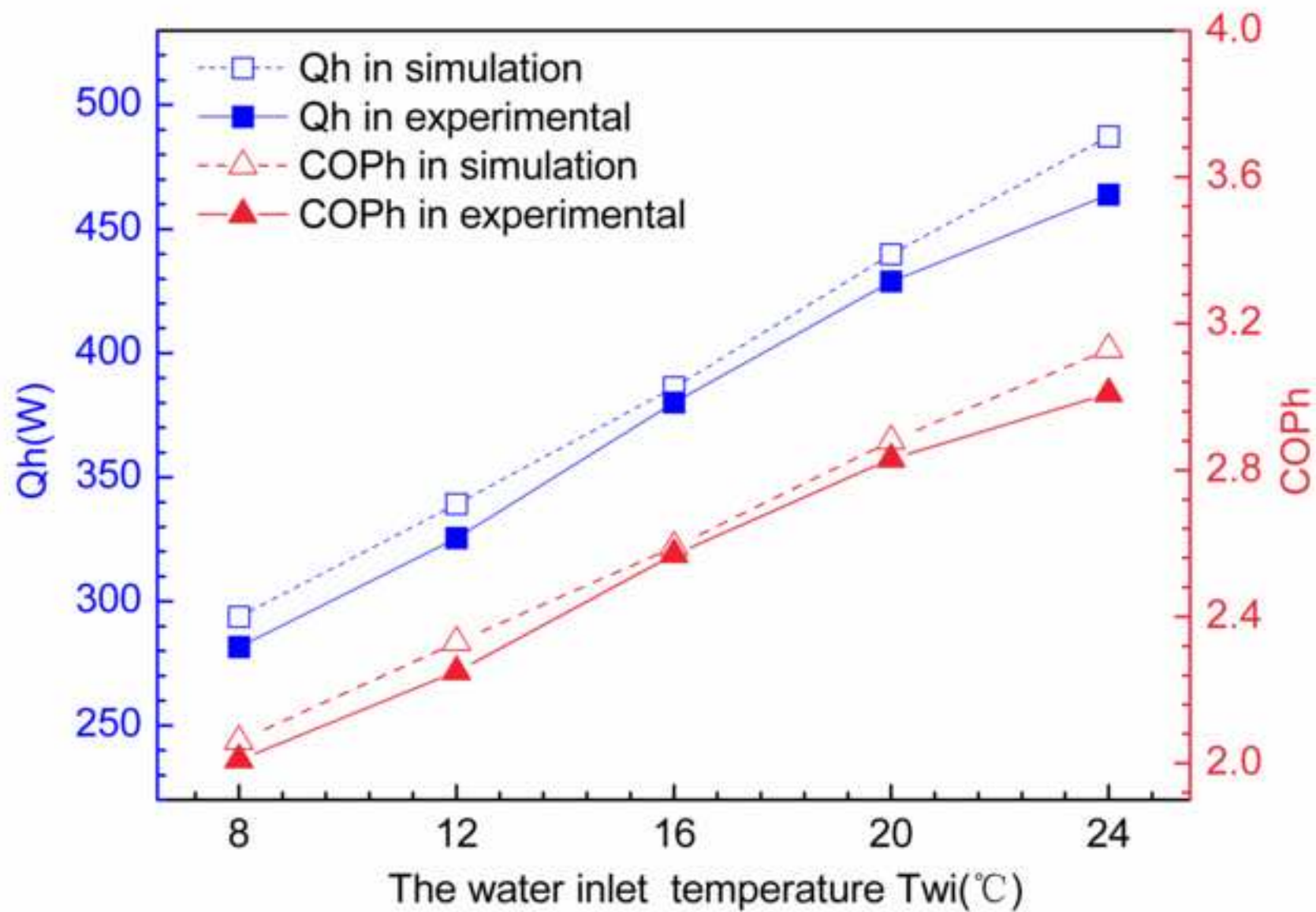
Figure(7)



Figure(8)



Figure(9)



Figure(10)

